Technology and Blooms taxonomy: tools to facilitate higher-level learning in chemistry
by Matthew Earle Morgan

A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Chemistry
Montana State University
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Abstract:
This research project ties together chemistry data acquisition technology, introductory chemistry laboratory experiments, and Bloom's Taxonomy of Educational Objectives into a unified learning model. The goal is to provide faculty and introductory chemistry students with the tools and exercises to experience higher levels of learning, as defined by Bloom's taxonomy. The tools developed as part of this project include data acquisition hardware and software, communications software, and computer simulations that enable higher-level learning situations.

A series of five experiments using a discovery-based teaching model are developed as part of the learning model. The experiments bring together the hardware tools, software tools, and learning model to place students in situations that require students to use critical thinking skills and experience higher-level learning. Content-related application problems are also included in the experiments. The experiments are divided into three chemistry units of instruction that build on each other, but can also be used independently.

Instructor training is an important part of this project. The successful integration of technology into educational situations cannot be accomplished without the support and understanding of faculty, staff, and teaching assistants. This aspect of the project focuses on shifting teaching and learning paradigms to encourage appropriate technology use and allow technology to become a major aspect of the high-level learning environment.

Finally, students were surveyed in an attempt to measure the effectiveness of the learning model. Students were evaluated on chemistry concept retention, as well as their perception of learning. They were also asked how well they enjoyed this form of learning.

Along with the tools themselves, this project provides templates that can launch future work in this area. The learning model, data acquisition tools, and experiment writing templates are developed here to provide curriculum builders many new ways to allow their students to achieve higher-level learning.

TECHNOLOGY AND BLOOM'S TAXONOMY:

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ABSTRACT

This research project ties together chemistry data acquisition technology, introductory chemistry laboratory experiments, and Bloom's *Taxonomy of Educational Objectives* into a unified learning model. The goal is to provide faculty and introductory chemistry students with the tools and exercises to experience higher levels of learning, as defined by Bloom's taxonomy. The tools developed as part of this project include data acquisition hardware and software, communications software, and computer simulations that enable higher-level learning situations.

A series of five experiments using a discovery-based teaching model are developed as part of the learning model. The experiments bring together the hardware tools, software tools, and learning model to place students in situations that require students to use critical thinking skills and experience higher-level learning. Content-related application problems are also included in the experiments. The experiments are divided into three chemistry units of instruction that build on each other, but can also be used independently.

Instructor training is an important part of this project. The successful integration of technology into educational situations cannot be accomplished without the support and understanding of faculty, staff, and teaching assistants. This aspect of the project focuses on shifting teaching and learning paradigms to encourage appropriate technology use and allow technology to become a major aspect of the high-level learning environment.

Finally, students were surveyed in an attempt to measure the effectiveness of the learning model. Students were evaluated on chemistry concept retention, as well as their perception of learning. They were also asked how well they enjoyed this form of learning.

Along with the tools themselves, this project provides templates that can launch future work in this area. The learning model, data acquisition tools, and experiment writing templates are developed here to provide curriculum builders many new ways to allow their students to achieve higher-level learning.

CHAPTER 1

INTRODUCTION

Since the beginning of organized education, educators and administrators have attempted to improve the learning process. In the last forty years a huge amount of time, effort, and federal funds have been devoted to this cause. Despite these efforts, increasing financial constraints on individual schools and colleges have made achieving quality learning more difficult. In many situations, lecture sections have become larger, while laboratory time has decreased. Students are primarily tested using machine-scored multiple-choice questions, and they rarely learn course material beyond the level necessary to answer these types of questions.

In an attempt to reverse this trend toward assembly-line education, the Advisory Committee to the National Science Foundation Directorate for Education and Human Resources has published a review of undergraduate education titled, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology.* The committee's stated goal is that "all students have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology, and all students learn these subjects by direct experience with the methods and process of inquiry." [1]

Two questions raised by this goal, then, are (1) How is "excellent undergraduate education" defined? and (2) How can schools, colleges, and universities cost-effectively teach using "methods and process of inquiry?" The purpose of this project is to address these two questions.

Higher levels of learning and thinking skills are defined in this project using Bloom's *Taxonomy of Educational Objectives*. The tools used to achieve higher levels of student learning are computer-assisted data acquisition and computer simulations. The emphasis on tool development is making data acquisition tools less expensive and easier to use.

All professors and school administrators want students to experience higher-quality learning, but the means and methods required to achieve this goal are often beyond the schedules and budgets of many colleges and universities. One method to achieve increased student learning is to use advanced educational technology to reduce demands on both time and budgets, and to place students in situations where they must use higher level thinking skills. Technology has been applied to many areas of education, including chemistry. Periodicals such as the *Journal of Chemical Education* and *The Chemical Educator* describe new methods and devices designed to measure chemical phenomena in an educational setting. Of all these innovations, the most influential technological improvement in chemistry education has been the inclusion of personal computers. A computer's ability to acquire, store, and analyze experimental data has markedly changed the way students learn in chemistry lecture and laboratory. Properly employed, computers are an important tool in enabling higher levels of student learning.

Computers by themselves cannot increase learning, however. Administrators cannot merely purchase computers, set them in classrooms, and expect the new technology to magically transform the nature of education. Improperly used, computers have resulted in lost productivity due to a distracting array of new features and time required to troubleshoot problematic hardware and software.[2] Critics of computer use in education assert that schools spend money on computers that have few functions beyond entertainment for teachers and students.[3] This combination of misperceptions and ill planning have resulted in disillusionment and potential abandonment of new technology for education.[4]

Educational technology exists in chemistry classrooms and laboratories, but its use and its potential benefits are not being realized. A recent survey of two-year and four-year university chemistry departments by Abraham and colleagues indicates that only 12 percent of the schools surveyed use computers in two or more laboratory activities.[5] This lack of use can be attributed to four main obstacles:

- Computers are expensive.
- Computer-driven applications can be difficult for students to understand.
- Few content-oriented applications effectively use new technology.
- Faculty have not had opportunities to learn to effectively use these tools.

Technological tools can benefit chemistry education, but these tools must be easily understood and properly employed in the educational environment.

Previous Work Incorporating Technology

Appropriate use of technology already has reaped great rewards in chemistry education. In the late 1980s, Amend, Furstenau, and others did pioneering work in applying computers to introductory chemistry laboratories.[6-9] They combined computer interface and sensor technology to develop a system for automated data acquisition and experiment design. The results of their work showed that experiments can be designed so that students using computers in the laboratory spend less time on data acquisition and more time designing experiments and analyzing their data. Expanding on this original work, a consortium of colleges and universities called Computers in Chemistry Laboratory Instruction (CCLI) created many experiments that make use of computer-controlled data acquisition.[10-14]

The inclusion of computer technology in the laboratory has enabled students at Montana State University and other schools to perform a greater variety of experiments and reduce the time required to perform specific laboratory procedures. Figure 1 shows that in traditional laboratory experiments, most of the class time is spent acquiring data. With the use of automated data acquisition, the time required to obtain data is significantly reduced, and more time can be allocated for student experiment design and data analysis (Figure 2).

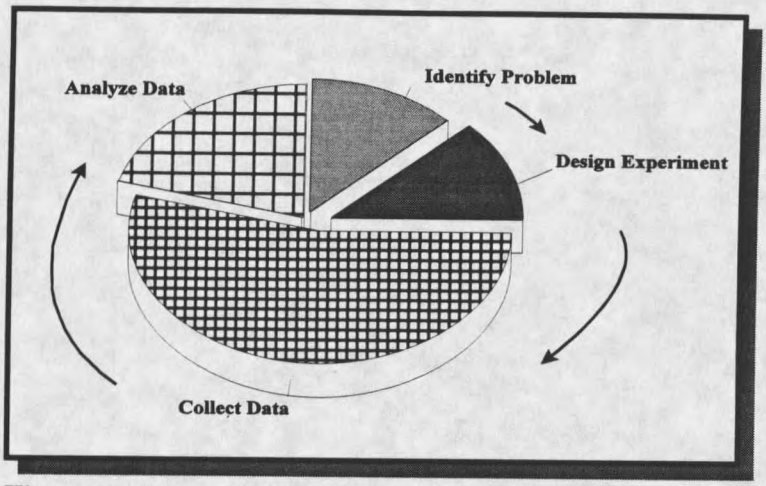

Figure 1. Time allocation for traditional experiments. Most of the laboratory time is spent on data collection, will little time left over for experiment design or data analysis.

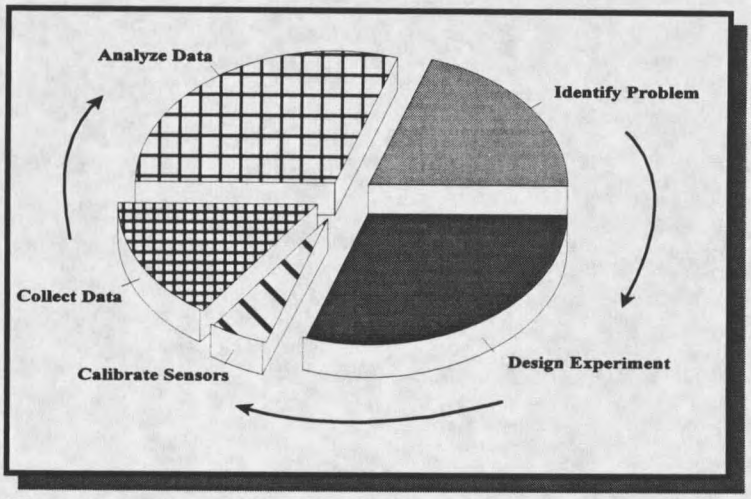

Figure 2. Time allocation for experiments using technology. Data collection time is reduced, and students may engage in higher levels of learning through experiment design and in-class data analysis.

Proper application of technology has also allowed the addition of final projects to MSU's laboratory curriculum. Students are presented with a brief description of a chemistry question, and then are required to design and implement an experiment to

measure a certain quantity and answer the question. In the winter of 1990, 650 introductory chemistry students were surveyed about their final laboratory projects. Seventy-five percent of the students surveyed believed that these projects were beneficial and should be continued.[15] The final projects continue to be a part of MSU's introductory laboratory curriculum, and a survey of 257 laboratory students taken in the spring of 1995 concluded that 74 percent of the students believed the final projects were worthwhile. At other schools, independent projects are now being successfully implemented into upper-division undergraduate physical chemistry courses.[16]

Technology, Accessibility, and the Learning Model

The goal of this project is to employ technology to enable students to engage in higher levels of learning using situations similar to those found in final laboratory projects. Technology, however, will not be widely incorporated into college laboratories unless the obstacles mentioned previously can be overcome. To make technology accessible, the following conditions must be met:

- The technology must be affordable.
- It must be easy to use.
- It must be relevant to the chemistry content taught in lecture.
- Faculty must understand how to effectively employ the tools.

In this project the first two conditions are met via the development of new data acquisition hardware and software. The third condition, chemistry content relevance, is addressed using a teaching model aimed at higher levels of student learning. A capable experiment model using technology should address four pedagogical issues: chemistry

content, the process of science, relevant applications, and active student involvement. Finally, all professors, teaching assistants, and laboratory managers must understand how the tools work.

In addition to being educationally sound, the teaching model must also be easy to implement. At McGill University in Montreal, Black and colleagues attempted to replace "cookbook" experiments with a completely unstructured approach to introductory chemistry laboratories.[17] Students devised their own projects and then carried them out. The educational philosophy behind this sort of laboratory exercise is sound, but the logistical load placed on the prep room staff makes this particular approach impractical. Chemistry stock room costs and labor requirements must be considered when modifying laboratory curricula.

The technology proposed in this thesis is also designed to benefit the myriad of students taking introductory chemistry courses. Traditionally, classes were primarily 18- to 22-year-old men and women who had little experience outside their homes and hometowns. These students had spent three-fourths of their lives in school, so they could be convinced to learn a concept simply because they were told to do so. Today, a single chemistry section can contain students whose ages range from young adult to late middle-age.[18] Many of these people have been out in the workforce, and they need to understand why learning chemistry is important, in both their present and future jobs, and in their everyday lives. Technology employed in the laboratory should also be relevant to the tools and instruments used in the modern workplace. The improvements proposed by this

project are directed at engaging both traditional and nontraditional students in the process of science.

Another barrier that must be surmounted is the negative attitudes of many teachers and students towards technology. Old teaching styles and expectations are not likely to work with new technology. Traditional teaching paradigms will have to be evaluated and possibly changed to enable higher learning using new technology. A shift in attitude must accompany new technology if that technology has any chance of being successfully used.

Project Description

This thesis presents ways to increase student critical thinking skills and learning levels through the effective use of technology, primarily for introductory chemistry laboratories. The project is divided into six areas:

- The Learning Model
- Improved Hardware
- Improved Software
- The Experiments
- Training and Instructional Philosophy
- Evaluation of Student Learning

The first goal of the project is to define higher level learning, and to apply a *learning model* that equates specific classroom actions to the thinking skills and levels of learning students achieve. To claim that students are learning at one level as opposed to another is difficult unless viewed in some form of context. In this project, the abstract concept of higher-level learning is applied in the context of Bloom's *Taxonomy of*

Educational Objectives. The taxonomy's learning levels form a backdrop for the activities made possible in student laboratories via proper use of new technology. The hardware, software, and experiments will enable students to learn at the higher levels described.

The *improved hardware* increases the use of technology by providing low-cost alternatives to existing equipment and enabling the measurement of physical quantities previously not possible. For example, control of the LabWorks interface has been expanded to include a hand-held Hewlett Packard HP 48 calculator, in addition to personal computer control. This set-up is ideal for laboratories that do not have the money or available space to use computers. In another improvement, low-cost turbidity measurements can now be made using the LabWorks colorimeter. Finally, a high-resolution temperature sensor gives a linear response to temperature changes as small as 0.001 Kelvin.

The *software improvements* section of this thesis describes how the World Wide Web is used as an administrative aid for teachers and as an information resource for students. Software also makes data acquisition technology "transparent" by providing a user-friendly interface. Context-sensitive help and an experiment design utility called EZ Program allow users to create experiment programs with merely a series of mouse clicks. Next, the computer as a simulation tool is explored, and the benefits of this application to chemistry education are described.

The *experiments* developed in this project apply the new hardware and software to chemistry concepts introduced in chemistry lecture courses. In addition to reinforcing

chemistry concepts, these experiments allow students to experience discovery-based learning. In this way, students are drawn into learning both chemistry content and the process of science in the laboratory. The experiments cover spectroscopy, colorimetry, turbidity measurements, dissolved gases, and environmental resources management.

Faculty training is another important part of this project. Without the support and understanding of professors and teaching assistants, technology can never be used to its full potential. The concept of paradigm shifting—the need for both students and teachers to adjust their expectations to match new technological tools—is explored. Many seminars and workshops have been conducted to educate college chemistry instructors about the benefits of properly used technology with the hope of changing their opinions on using technology. These workshops allow faculty to evaluate the effectiveness of teaching models that employ laboratory technology, and see first hand how the teaching model can meet their individual needs.

The last part of the project, *evaluation of learning*, validates the model by assessing student performance. Accurately measuring higher learning levels using traditional testing methods is a difficult prospect, but the exercises provide valuable information.

Statements of Original Work

This project requires creativity and input from many different sources. The tools developed here are a combination of original work of the author, collaborative efforts of the author and others, and sometimes original applications of tools developed by others.

Chapters describing the development of new hardware tools, software tools, and experiments include a section that distinguishes original work, collaborative efforts, and applications of existing tools.

Taken together, all parts of this project allow new technology to be successfully employed in introductory chemistry laboratories. The short-term benefit from this project is the technology— the hardware, software, and experiments. The long-term gain comes from the model that ties technology to a well-known and accepted classification of learning levels. Correct implementation and application of technology based on this model will benefit administrators, teachers, and most importantly, students.

CHAPTER 2

A TEACHING MODEL BASED ON BLOOM'S TAXONOMY

Defining and quantifying educational goals and standards is a difficult, but extremely important, aspect of education.[19] Among the myriad systems of classifying teaching strategies, Bloom's *Taxonomy of Educational Objectives* has been an effective benchmark used to identify levels of learning. This chapter provides a synopsis of Bloom's taxonomy, examples of previous work using the taxonomy in science education, and a description of how the taxonomy is used to compare the tools developed in this project to those of traditional chemistry curricula.

Synopsis of Bloom's Taxonomy

Since its publication in 1956, the *Taxonomy of Educational Objectives* has profoundly influenced educators. The original taxonomy was broken into three distinct parts: cognitive, affective, and psychomotor. The cognitive domain concerns the process of learning and developing thinking skills. The affective and psychomotor domains refer to the appreciation of knowledge and the ability to perform hands-on tasks, respectively.[20] All work in this project relates to the cognitive domain.

Bloom's taxonomy (referred to in this thesis as "the taxonomy") presumes that students can learn information at different degrees of mastery. The taxonomy identifies six levels of learning, ranging from simple memorization to higher forms of learning such as synthesis and evaluation:

- Knowledge
- Comprehension
- Application
- Analysis
- Synthesis
- Evaluation

These levels build on each other. For example, a student who learns a concept at the comprehension level also understands at the knowledge level. Figure 3 illustrates the hierarchical relationship among the six levels.

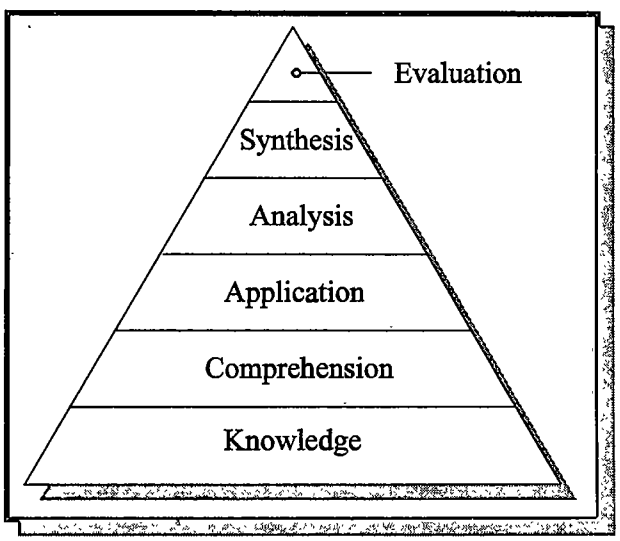

Figure 3. The six levels of learning according to Bloom's taxonomy. Evaluation requires the highest level of thought process.